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PAPER

An Ensemble Filter for Indoor Positioning Technology of Mobile Home Service with Agile iBeacon Deployment

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ABSTRACT

In this article, we undertake a thorough investigation into the theory of indoor location, adopt an effective and quick positioning algorithm, and make use of a network of low-power iBeacons. An iBeacon-based indoor positioning system (IPS) is presented to investigate how to utilize iBeacon for accurate location and whether it can successfully replace the current dominant positioning technology based on the analysis that was conducted. However, the first things that should be taken into account at this point in the design of house robots for indoor environments are how to quickly and precisely gather target node location information as well as how to regulate and plan a course. This article examined the more popular and often used indoor positioning techniques, provided a succinct summary of current indoor positioning technologies and regulators, and examined ultrasonic locating technology in depth. Based on this, a system for mobile home service robots was developed, and simulation tests were performed to assess the accuracy of node locating, node reception and arrival times, the best level of route planning, and navigation and path estimation errors in both absolute and comparative terms. Additionally, we go into detail about the difficulties in developing a practical IPS, the solutions that are already available, a thorough performance comparison, and some potential future IPS development trends.

KEYWORDS

iBeacon deployment, indoor location, mobile home service, accuracy, navigation, Bluetooth Low Energy (BLE)

1 INTRODUCTION

The increased usage of telephones and other wireless devices in recent years has sparked the development of several offerings, including indoor localization. Indoor localization is the process of identifying an item or individual inside a structure or other indoor setting. Indoor device localization has been extensively researched over the past few years, mostly in manufacturing settings and for mobile networked sensors and robotics. It has only been a little more than ten years since the widespread

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adoption of smartphones and Bluetooth-enabled linked watches made it possible to localize and track both the gadgets and the individuals who use them, opening the way to an extensive variety of related applications and services [1]. Operator and device localization is widely used in the health sector, business, emergency planning, building management, monitoring, and many other sectors. It can also help a variety of cutting-edge systems, including machine-to-machine communication (MTC), the IoT, and smart architectures (including smart grids, intelligent structures, and intelligent cities).

Due to the complexity of the indoor setting, multipath transmission, and the shadowing impact on a radio signal, these phenomena are frequent [2]. As a result, both line-of-sight (LOS) and non-line-of-sight (NLOS) indication gears may be present in the received signal. This leads to less precise time synchronization, making propagation time measurements problematic for IPS systems that rely on time of arrival (TOA), time difference of arrival (TDOA), and angle of arrival (AOA) signal measuring principles. Due to the combination of multipath signals with different phases, the received signal strength (RSS) is also unstable. Additionally, the magnetometer in the smartphone must be properly calibrated, and the magnetic pulse has very limited discernibility.

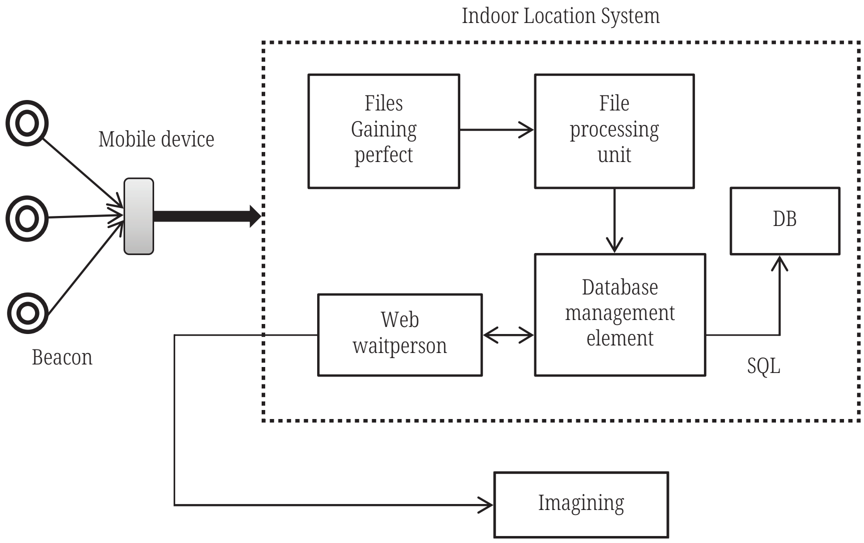

Fig. 1. Design of the suggested indoor positioning system

There are three primary components to the recommended indoor positioning system. A data gathering module first compiles the beacon received signal strength indicator (RSSI) readings that handheld gadgets have made. Following data correction via the filter algorithm, a data processor module applies a positioning approach using the filtered findings. The third important component, the data administration module, organizes and maintains the data processor to produce a relational database. The proposed scheme's construction is shown in Figure 1.

Even though GPS performs well in open areas, it is challenging to pinpoint a user's location in an enclosed area since indoor signal reception is erratic. As a result, numerous indoor positioning systems are now being investigated and developed to replace GPS. Installing Bluetooth connectivity, audio waves, and other signal-transmitting devices indoors and then utilizing wireless and mobile phones like Wi-Fi radios and smartphones to receive those signals to compute user position is a common method of indoor positioning technologies. Conversely, a different technique uses technology that is integrated into the devices to determine the user's position. The earlier method can provide more accurate location data, but it also requires more installation work and expenditures for additional equipment. Although there is no need for extra equipment and the cost is lower with the latter option, positioning steadiness and accuracy are poor. Furthermore, because of the constant calculating procedures, the components can cause the user's scheme battery to soon run out. [3]. There are methods utilizing BLE beacons among the indoor locating approaches.

This paper's remaining sections are organized as follows: Section 2 assesses the pertinent literature, and Section 3 outlines the utilization of beacons, as an indoor location strategy. The platform's implementation details and the simulations used to assess the efficiency of our proposed algorithm are presented in Section 4 and the conclusion in Section 5.

2 RELATED WORKS

Kwok, C. Y. T., Wong et al. [4] By connecting the transmitter's distance and device ranges calculated from the RSSI, triangle trilateration locates the object. The results of the experiments revealed that the signal strength measurements for iBeacons vary greatly depending on the manufacturer, mobile OS (Android or iOS), installation environment, and use cases, even if they have the potential for accuracy in closeness and distance predictions. They discovered that RSSI readings for the Apple and Android operating systems fell at the highest TX strength of 3 dBm at 1.3 m elevation; various rates are seen as the distance and transient variance increase. According to accuracy studies of BLE for indoor locating applications, the three authorized BLE marketing channels' limited bandwidth is what causes a substantial amount of measurement errors.

Sukreep, S., Nukoolkit, C., et al. [5] compute the user's potential location using a Wi-Fi access point (AP). This approach, which has gained popularity for indoor placement since it was initially employed in 2002, was developed thanks to the APs' quick growth. Wi-Fi-based techniques have been employed by several researchers. The robust mean of the sum-RSS (RMoS) technique, for example, uses mobile objects to determine the location while considering either a fault-free situation or a reference node (RN) breakdown. In 2009, indoor positioning utilizing RFID, a straightforward technology utilizing radio frequency scanners and tags, gained popularity. This method has a high rate of detection. But RFID is a costly innovation that is also intrusive. Additionally, RFID's low-efficiency messaging range

Blasio, G. D., Quesada-Arencibia, A., et al. [6] There are numerous studies on BLE-based indoor positioning, including the initial step of setting up tests of fine-grained BLE setup and conducting a comprehensive analysis of the key elements for accurate indoor positioning using BLE radio communications. These studies fall under the particular group of fingerprinting-based studies. The practicality of location using biometrics combined with squared Euclidean measurements for matching templates with the acquired signal intensity of BLE beacons. Regarding studies of environmental or beacon-related parameters, when constructing BLE4.0 beacon-based indoor location processes, the authors identify in a simple setup the key system element to take into account and look at two variables: broadcast intensity and situational physical properties.

Manek A. N., Devikar, M., et al. [7] have reported the availability of an Android-based iBeacon Analyzer app. For each iBeacon it can find, this tool compiles statistics on the temporal and spatial variance of the RSSI values shown on the Android-enabled handheld device. It looks into how the BLE protocol can be used to create wearable technology with high data throughput demands, such as those found in health-related apps. To gain a basic understanding of beacons and determine whether position estimation is feasible, many BLE beacon devices are installed inside and outside of a space. These beacons are then observed by portable electronics using RSSI. They illustrate the luggage monitoring use case for iBeacons and assess the advantages and disadvantages of doing so.

Sjöbro, L. et Al. [8] use the standards of the nearby WiFi APs' RSSI to create the fingerprints, which are subsequently saved in radio map databases. The individual is then located using the database and the fingerprints that have been saved. The time required to conduct a site survey is one of the drawbacks of radio map-based systems that are mentioned in the article. They also emphasize that if new emitters or other structural modifications are made, the database needs to be updated. This is necessary because if the RSSI values were different, they would no longer serve as reliable signatures and would need to be recollected. However, due to the great accuracy that can be attained with a fingerprint-based locating system, the benefits outweigh the drawbacks.

Zhang, X., Zhang, S., Wang, C., et al. [9] state tht high-precision geo-location services have been integrated into all facets of business and daily life thanks to the ongoing advancement of ground-based stations and the use of modern communication technology. A precise laboratory design based on the GNSS CORS network was proposed. The "SoBDS" platform is built in conjunction with the ongoing needs of the HNCORS network. A decimeter-level sample experiment demonstrates the system's good interoperability and scaling, as well as its potential to serve a million customers. The technique increases positioning precision by combining ambiguous location information from biometrics and DR. The presentation of the SKPF algorithm is similar to that of the PF method, and it has higher computational effectiveness than the PF algorithm. It also has greater positioning precision than the KF and UKF algorithms.

Paek, J., Ko, J., & Shin, H. et al. [10] argue that providing proximity-based services for applications and coarse-grained indoor location placement and navigation based purely on proximity is the initial goal of iBeacon technology. Keep in mind that location (where you are) and proximity (being close to an object) are connected but not always the same. Unlike closeness, an address (or location) is an absolute value that is typically determined by some kind of coordinate system (such as longitude and latitude for GPS). However, there are currently several suggestions to use BLE for indoor positioning, expanding the number of earlier efforts that employ other technologies like WiFi, GSM, RFID, IEEE 802.16.4, and earlier iterations of Bluetooth for indoor positioning.

3 METHODS AND MATERIALS

Through the application of an indoor positioning system that the researchers created, the efficacy of existing indoor positioning methods was assessed, as was the pursuit of more effective positioning approaches. The system makes use of Bluetooth technology, in particular transmitters known as beacons that send radio signals to neighboring gadgets. These signals carry data, including the beacon's RSSI intensity and its unique beacon identity.

3.1 Technology for indoor positioning

No positioning technology is capable of meeting the practical requirements of humanoid location-based services in complicated town contexts on its own because of the particular limitations of positioning technologies. To do this, the researchers suggest the idea of seamless localization. In settings where people often interact with objects, including retail centers and underground parking garages, seamless positioning technology combines two or more location techniques. Users can simultaneously receive positional signals in any situation or environment. High availability and precise placement are eventually made possible by the seamless connection it offers and the fluid switching between positioning techniques.

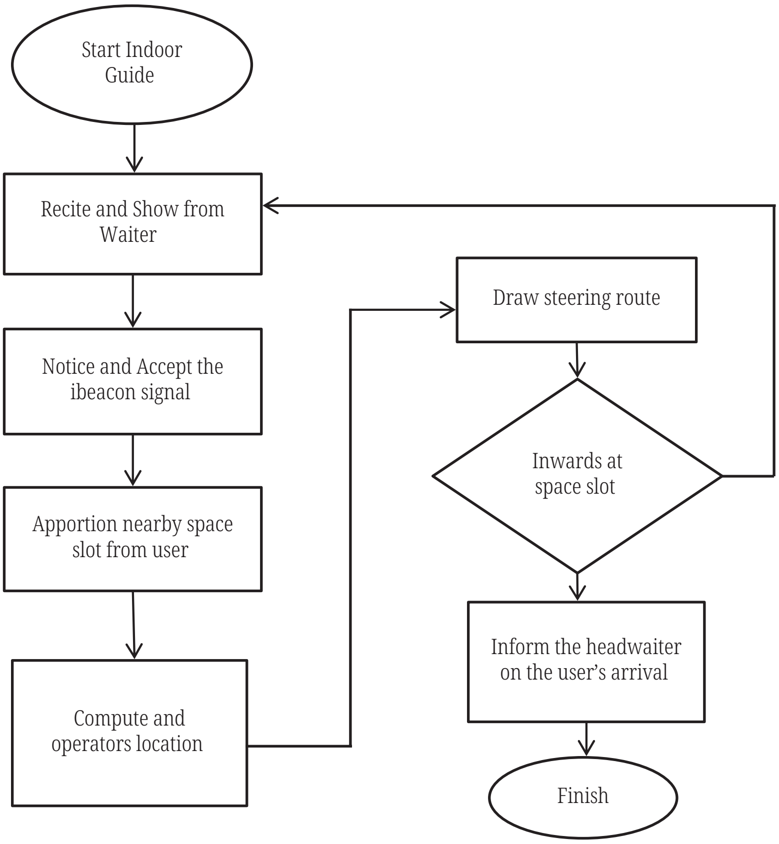

Fig. 2. Indoor placement flow-chart

A crucial component of indoor positioning is figuring out the target's location when it is in the interior environment's reference frame. Many individuals utilize WiFi to make location estimates for things in indoor settings [11]. This is due to the increased geographical coverage of WiFi network transmissions. Radio waves can pass through the majority of obstructions since they have a significant ability to penetrate. The two categories of indoor positioning architecture are base station type and mobile interface type. The four components of positioning and ranging data are the TOA, the TDOA, the DOA, and the RSSI. Figure 2 depicts the process of indoor placement.

The WiFi range placement algorithm is based on knowing how far each WiFi AP node is from the target. By using the AP node's known location as a starting point, it calculates the target's parameters. Trilateration, hyperbolic measurements, and the least-squares method are the most fundamental localization methods.

Phase of Segmentation. The technology employs the smartphone's internal sensors to measure the user's movement after locating the starting place by looking for anchorages.

By reading of the velocity device t and the next equation, the system estimates the distance *ft* at time f:

$$f_t = \int_{f-2}^{f} \int_{f-2}^{f} \partial_f \partial_t . ft \tag{1}$$

IPSCL uses information from the geomagnetic sensor and the gyroscopic sensor to determine the worth of the present headed track *t* by using the standards of the prior headed direction t_1.

$$Vali^{accell} = \{u^{accell}, v^{accell}, z^{accell}\} \tag{2}$$

$$Vali^{accell} = \{m^{accell}, n^{accell}, o^{accell}\} \tag{3}$$

Where, accordingly, *m*, *n*, and *o* stand in for the sensor data collected on the respective axes of the phone [14]. IPSCL translates these data from the device coordinates to the reference scheme described as a straight orthonormal base because they are measured about the smartphone's screen. These calculations are made using the IPSCL R rotational matrix of 3 by 3.

$$S = \begin{vmatrix} S_{00} & S_{01} & S_{03} \\ S_{09} & S_{10} & S_{11} \\ S_{20} & S_{22} & S_{16} \end{vmatrix} \tag{4}$$

The results from the altimeter and geomagnetic sensors are used to calculate the initial column of the matrix *R* in the manner described below:

$$\begin{aligned} S_{20} &= u^{accell} * num_1 \\ \int S_{21} &= u^{accell} * num_1 \\ S_{22} &= u^{accell} * num_1 \end{aligned} \tag{5}$$

$$num_1 = \frac{2}{\sqrt{(u^{accell}) + (v^{accell}) + (x^{accell})}} \tag{6}$$

Finally, the first and third rows are used to determine the second column of matrices *S* in the following manner:

$$\begin{aligned} S_{10} &= S_{21} * S_{02} \\ \int S_{11} &= S_{22} * S_{00} \\ S_{12} &= S_{23} * S_{21} \end{aligned} \tag{7}$$

When the spinning matrix is finished, IPSCL calculates $\varnothing_l^{mag}$ using the formula:

$$\varnothing_l^{mag} = atan3(S_{00}, S_{11} \tag{8}$$

val_l^{gyro} is calculated using data from the geomagnetic and accelerometer sensors. The smartphone measures val_l^{gyro}, the value of the accelerometer sensor when it notices a change in its readings. The speed value known as $\varnothing_l^{mag}$ represents how quickly the heading of the direction changes over time *t*. IPSC uses the following equation to determine the variable value "*gyro*":

$$\varnothing_l^{mag} = \int_{f-1}^{f} val_l^{gyro}.ft \tag{9}$$

3.2 An indoor positioning system using BLE beacons

The three main components of these indoor positioning systems that make use of BLE beacons are shown in Figure 3: (A) the BLE inspiration surroundings; (B) the indoor putting component, which establishes the operator's location using beacon statistics gathered through the mobile application; and (C) the indoor advertising data analytics unit, which derives and assembles fresh data from the collected information.

Every user's time spent in the study's indoor environment is specifically recorded as a separate user interval, which contains all the data collected from their handheld devices as they moved indoors and passed by the implanted beacons. The smartphone app is designed to record broadcasts from nearby beacons to pinpoint the user's location.

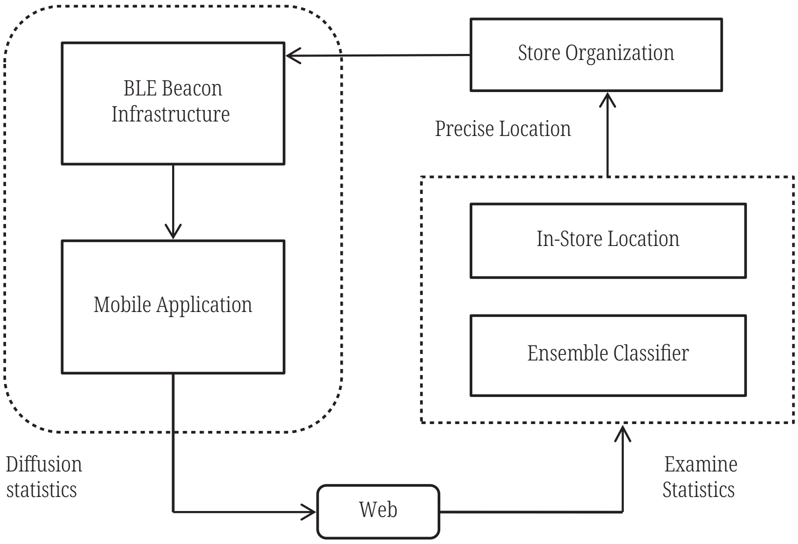

Fig. 3. Overview of the BLE beacon-based indoor locating systems

The indoor location module, which is integrated into the backend, then first gathers and saves the aforementioned mobile device's unique identifier and any beacon data generated during the user's sessions. This module's main component, the indoor locating technique, gathers and filters information gathered from beacon events to determine the user's device's indoor status, particularly where it is located [15, 16]. This study looks at the indoor positioning component in particular and the positioning method it uses. The approaches that facilitate effective indoor placement are suggested after an evaluation of the current ones. To do this, a genuine BLE-based indoor location system that tracks customers using mobile devices in grocery stores was developed and put into operation [17, 18]. A hybrid technique that improves customer interior localization in the store was proposed using the produced light data for evaluating indoor navigation tactics.

4 IMPLEMENTATION AND EXPERIMENTAL RESULTS

In this study, the planned mobile home service robot is simulated using MATLAB simulation tools. The computations and simulation testing treat the robot as a weight point, and the barriers expand to a distance that is half of the robot's maximum dimension.

Table 1. Information about the test elements' coordinates in space

Scope	Nodule Type	Position Information
Three – Dimensional space 1	Nodule 1	(4,2)
	Nodule 2	(1,4)
	Nodule 3	(0,6)
	Nodule 4	(7,1)
	Nodule 5	(3,0)

To determine the robot's time of signal reception and TOA for every node in both areas, the test nodes are installed in each of the robot's two three-dimensional spaces' five compartments.

Table 2. Information about the test vertices' coordinates in space 2

Scope	Nodule Style	Position Information
Three – Dimensional space 2	Nodule 1	(6,6)
	Nodule 2	(3,2)
	Nodule 3	(4,0)
	Nodule 4	(2,5)
	Nodule 5	(7,4)

The spatial center is used as the origin for calculating precision in node placement, level of ideal routing, relative and relative navigational errors, and path prediction. Tables 1 and 2 provide the coordinate data required for each node.

Table 3. Size of barriers in each section of 3D spaces 1 and 2

Scope	Nodule Type	Position Information
Three – Dimensional space 1 and space 2	Separation 1	51 cm * 35 cm
	Separation	59 cm * 44 cm
	Separation	59 cm * 44 cm
	Separation	35 cm * 25 cm
	Separation	26 cm * 17 cm

The first test was carried out in three-dimensional territory 1, where barriers were positioned in each division with a moderate degree of difficulty; the second test was carried out in three-dimensional location 2, where difficulties were positioned in each split with a high degree of difficulty and an advanced level of trouble. Table 3 displays the details of each obstacle's height.

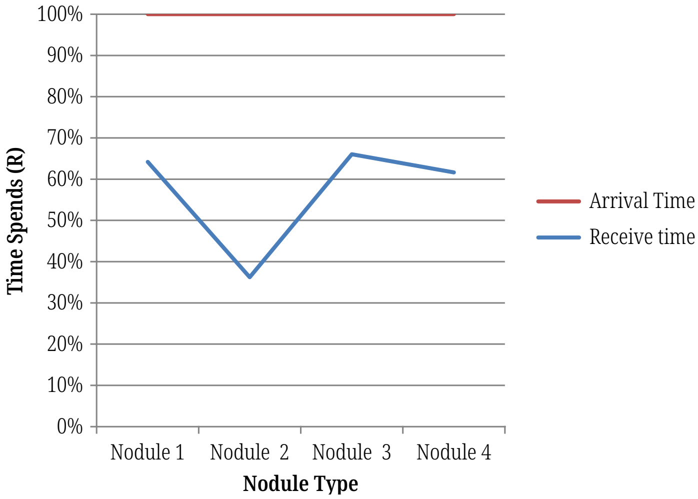

Fig. 4. Check results for signal reception and ultimate arrival time

Figure 4 shows the test findings for receiving signals and arrival time in spaces 1 and 2. It demonstrates how the mobile home service robot is ideal for gathering signals from all nodes in the three-dimensional space with only a tiny bit of trouble setting boundaries [12, 13]. The time it takes to receive a signal varies between 1.89 seconds and 2.67 seconds, with the distance variable being the main cause of both extremes. It takes between 9 and 10 minutes for the signal to reach the node after being received. In the confines, the mobile home service robot takes somewhat longer to receive instructions and go to the node's position in three dimensions, where the challenge of setting up challenges is high, which also demonstrates that the precision of recognition inside the framework of robots has a beneficial effect on the actual motion process of the machine.

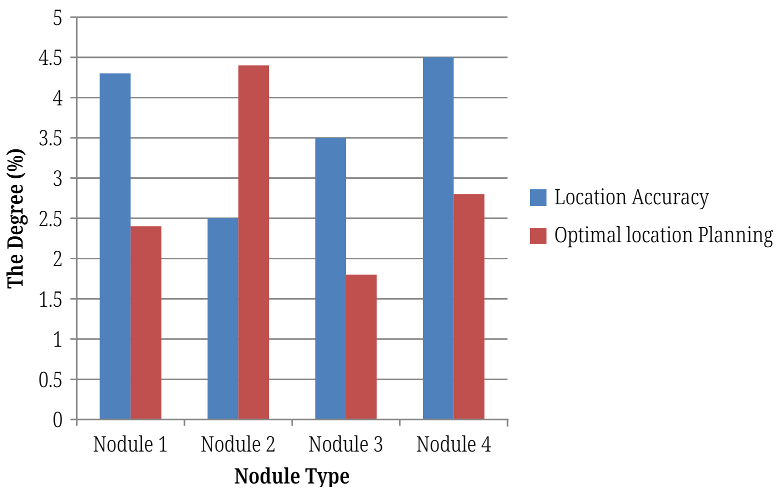

Fig. 5. Test outcomes for node location accuracy and optimal level of planning routes

The precise positioning and optimal level of planning for the route in spaces 1 and 2 were tested, as shown in Figure 5, and the mobile home service robot is perfect for receiving messages from each node in the three-dimensional area with just a minor amount of difficulty in setting barriers. The time it takes to receive a signal varies between 2.89 seconds and 3.67 seconds, with the distance variable being the main cause of both extremes. The interval between receiving the signal and reaching the node is kept between 12 and 14 seconds. In three-dimensional space, where establishing obstacles is difficult, the time it takes the mobile home service robot to receive messages and reach the node increases somewhat. This further demonstrates that the accuracy of recognition within the robot system has a positive impact on the actual moving process of the machine.

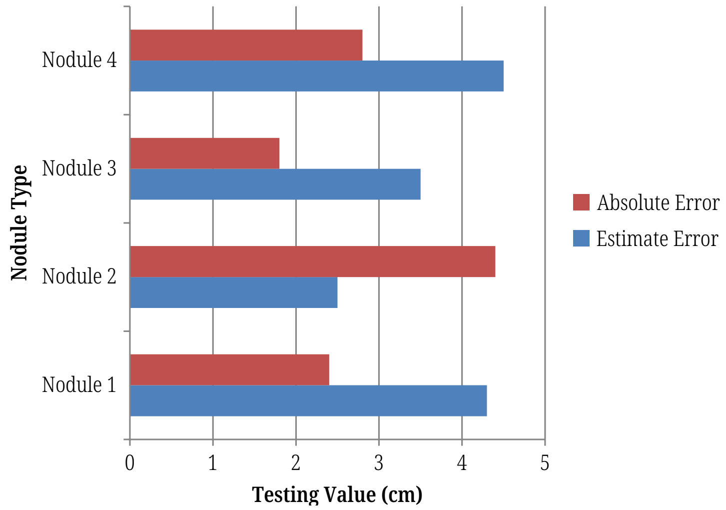

Fig. 6. Results of the navigating and dead-calculating absolute mistake tests

Figure 6 shows the trajectory and dead-counting test outcomes in space 1 and space 2. The mobile home service robot's highest relative error in space in three dimensions is 6.28%, while its least relative error is 2.31%; similarly, the highest value comparative error of the dead counting is 6.74%, while its least relative error is 3.21%. The greatest relative error of dead counting in space 2 is 5.11%, and the least relative error is 3.32%. The supreme comparative error of navigation in Space 2 is 6.99%, and the smallest relative error is 4.41%. The information presented above shows that the actual location of the node within the robot system is not far from the calculated value, demonstrating that the mobile home service robot proposed in this paper can be used indoors and that the system's navigation estimation precision is generally high.

5 CONCLUSION

The indoor positioning method and technology are examined in this research, and a mobile home service robot is developed as a result to increase the positioning precision of the entire system. This article examines the interior placement of customers utilizing a BLE beacon-based indoor placement system in a real grocery retail shop with two floors. There are still many issues with this study, despite the substantial research that was done on indoor location technology and mobile home service machine administration. The study reported in this publication lacks appropriate breadth and depth. The steps in this study's methodology were choosing and gathering experimental results under the most perfect circumstances possible, but its validity and reliability were insufficient, and some interference variables that were present during the test process were not taken into account. According to the degree of technology already available, future work will examine acceptable placement methods and means from more angles to continuously raise the caliber of investigation.

We haven't placed many restrictions on indoor placement yet because we want to show how iBeacon and smartphone sensor raw data can be improved. As a result, a specific human mobility model could be used to forecast how people will travel, and map constraints would be taken into account when calculating the likelihood that people will transfer between different sites. We'll also look into other fusion methods for indoor positioning, such as grid-based filters, for real-time applications. Finally, alternative data sources, including geomagnetic data, can be added for fusion.

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